Flooding and gas emissions of old iron mines in lorain

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FLOODING AND GAS EMISSIONS OF OLD IRON MINES IN LORAIN

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ABSTRACT: A study carried out in the iron basin of Lorraine (North-East of France) enlighted on the existence of under-oxygenated and noxious gas emissions (carbon dioxide, radon) in vast built-up areas related to abandoned mine workings. This study has been extended to other sectors of the Lorraine basin, the northern region, which is currently subjected to flooding. Specific devices were put in situ to observe the gas flow characteristics. The natural thermal convection seems to be the main phenomenon to explain the gas circulation. Noxious gas is also emitted but the intensity of the phenomenon was far less spectacular than those observed in Moyeuvre-Grande area.

KEYWORDS: gas, emission, iron mine, natural thermal air circulation

RESUME : Une étude a été menée sur le bassin ferrifère lorrain (Nord-est de la France). Elle a mis en évidence l'existence d'émissions de gaz viciés ou sous oxygénés (dioxyde de carbone, radon) dans des zones urbanisées en relation avec les vieux travaux. L'étude a été étendue à d'autres parties du bassin et en particulier à la partie nord. Des dispositifs spécifiques ont été placés in situ afin d'observer les caractéristiques du flux de gaz. Le tirage naturel thermique semble être le mécanisme principal qui explique la circulation du gaz. Du gaz vicié est émis mais dans des proportions bien moindres que celles observées dans la zone de Moyeuvre-Grande.

MOTS-CLEFS : gaz, emission, mine de fer, tirage thermique naturel

1. Introduction

Built-up areas of the iron basin of Lorraine (France) (figure 1) are affected by emissions of polluted air: gas mixtures under oxygenated and noxious gas emissions (CO_2 and radon). The most spectacular phenomenon occurred in the built-up area of Moyeuvre-Grande, in Moselle, especially the district of the town located very close to the former underground mining works.
They were translated by faulty working of gas cookers and boilers. So, it have been measured within cellars in connection with old mine workings, high level CO_2 content (up to 6 %) and low level O_2 content (down to 13 %).
During the same time, measures made by the Institute for Radioprotection and Nuclear Safety (IRSN) and the DASS (governmental organisation under Ministry of Health) investigated and measured high level radon content (up to 20 000 Bq/m^3) in the gaseous mixture. In some cases, these emissions affected directly buildings in connection with mine entrances or with the old superficial mine workings.

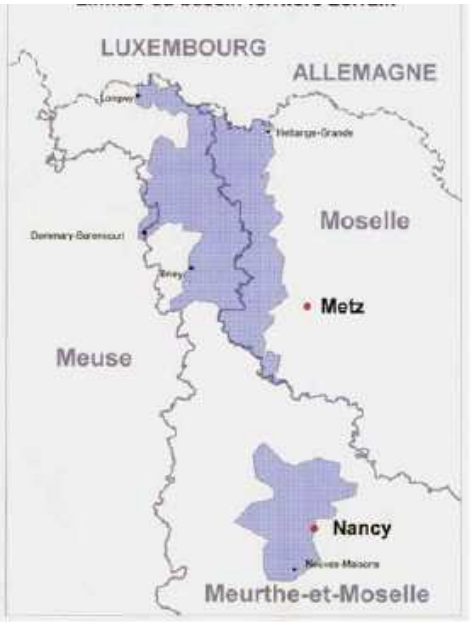

Figure 1. Ferriferous lorrain basin limits

Following the Lorraine local office of the French Ministry of Industry, Research and the Environment (DRIRE) request, INERIS started in 1999, some investigations to assess the scale and the geographical extent of the problem. First study was focused on the nearby reservoirs of "Rosselange", Franchepré and "Orne".
Then, investigation was made in non-flooded reservoirs of the Northwest part of the ferriferous basin: Mexy, Lexy and Godbrange. These investigations showed that, in these areas, similar emissions to that observed in Moyeuvre-Grande were occurring. However, the intensity of the phenomenon was farless spectacular than those observed in Moyeuvre-Grande area (Pokryszka et Grabowski, 2002).
INERIS is now carrying out research to understand the phenomenon of gaseous emissions from iron mines. These works are realised in the framework of a program funded by the French Ministry in charge of Industry, in collaboration with the local administration (DRIRE) and GEODERIS.
These works also join within the framework of the research program GISOS. Today, monitoring continues by means of two devices of measure set up in the past on the site of G7 and G37 adits. The flooding of the north iron basin which began in December, 2005 was the occasion to identify if the north basin would be also subject to these particular gas emissions
In this frame, it was decided to instrument 4 openings in connection with the mining voids of this part of the basin. The interest of such instrumentation was to monitor simultaneously, on several points of the same reservoir subjected to flooding, entries and releases of gas.
Taking advantage of the acquired experience on the reservoir of Moyeuvre-Grande, specific devices of measures were developed and set up in representative points of that reservoir.

2. The risks created by gaseous emissions

In an average atmosphere, the volumetric oxygen is 20,9 % and the carbon dioxide one is 0,03 %. The consequences on health of a CO_2 enrichment and an O_2 impoverishment are multiple and vary in gravity according to the amount of these two gases.

It ranges from heads headache, for CO_2 contents between 3 and 4 % and O_2 content between 14 and 16 %, and to death for O_2 contents lower than 6 % and CO_2 higher than 10%. Concerning radon, the risk of lung cancer increases proportionally with the exposure.
Colligan and Pirard (2005) considers that the risk of cancer increases by 16 % by edge of 100 Bq / m^3 for an exposure between 5 and 34 years before.
These observations induced INERIS to carry on its investigations by putting the various openings a station of measures and acquisition.

3. Measure and acquisition devices

3.1. Devices

Every device allows to measure and to register the parameters of the outgoing gaseous flow through the instrumented opening. We used the experience acquired in Moyeuvre and Tressange to conceive these devices.
The devices are constituted by the following elements:

- pipes to forward the gas pumped inside and to drive towards the various sensors;
- a set of sensors to characterise the gas flowing through the adit or the shaft (temperature, sense of drainage, speed, composition and differential pressure);
- a set of sensors to measure the weather conditions (outside temperature and barometric pressure);
- a set of power supply;
- a system of acquisition and storage of the data.

All the components are put together in a cupboard of protection before on-site installation.

3.2. Measured parameters and scale

To measure the parameters influencing gas flow and its characteristics, every station (cf. photo 1) includes the measure of:

- the atmospheric pressure between 600 and 1060 hPa; it is measured by means of a barometric pressure sensor;
- the differential pressure between inside and outside of the mining works, on the range -20 +20 Pa which can be extended to -50 +50 Pa;
- the oxygen content, on range of measure from 0 to 10 %, measured with a infrared sensor;
- the volumetric activity of radon, on the range of measure from 0 to 100 000 Bq/m^3; measured with a probe Barasol;
- the gas temperature, on the range of measure -20 to 60 °C; measured with a thermo-couple;
- some stations are equipped with an anemometer intended to measure the sense and speeds of gas flowing in order to evaluate the gas flow. This equipment can measure speeds until 65 m/s;
- the ambient temperature is measured on-site with a thermo-couple.

Photo 1. Measuring station and anemometer in Algrange adit

4. Moyeuvre- Grande case

In order to find the origin of the flow driving the gaseous exchanges between the old mine workings and the atmosphere, two measuring stations were installed in the entry of two former adits connected to the reservoir of Moyeuvre-Grande.
Figures 2 and 3 show some interesting results obtained from the data collected since April 2000.
These results show that it exists clearly a correlation between the sense and the intensity of the air flow and the outside temperature. No other parameter, having a significant effect on the flow has been identified.
This observation intends to consider the natural thermal convection as the phenomenon playing an essential role in the creation of the gaseous flow between the mining reservoirs and the surface. This phenomenon is due to the thermal differential existing between the external atmosphere and the old workings.
In the old workings, the temperature is usually almost constant (it is estimated in 12-14°C, in our case), contrary to the atmospheric temperature, whose general level varies according to the annual seasonal cycle. Also, a topographic configuration of the surface over the mining reservoir of Moyeuvre-Grande and the other concerned reservoirs seems to facilitate the thermal convection.
Indeed, the investigated areas are characterised by a very contrasted topography with rather large plateau, interrupted by an irregular network of valleys. The ferriferous deposit is located at the base of the plateau, with emergences appearing frequently on the hillsides of valleys.
During summer, a part of the atmospheric air in contact with the upper old workings (openings badly or not filled cracks) is subjected to a progressive cooling. An increase of the bulk density, due to the effect of cooling, causes gas migration of gas towards the lowest parts of the old emerged mine workings.

Then, the gas goes out of the mining reservoir by through the various openings situated mainly along the outcrops with in valleys. A circulation of air so becomes established.
The functioning of the reservoir according to this model is characterised by two particular and different stages:

- the summer period, during which the flow is globally coming out of the massif. It corresponds to an outside temperature significantly superior to that inside one (approximately 14°C);
- the winter period, during which the flow is globally coming into the massif. It corresponds to an outside temperature significantly superior to that inside one (approximately 14°C);

These two very different periods are separated by transition time, during which the flow is fluctuating.
Figure 2 presents the most interesting results obtained from the nonstop measures made since April, 2000.

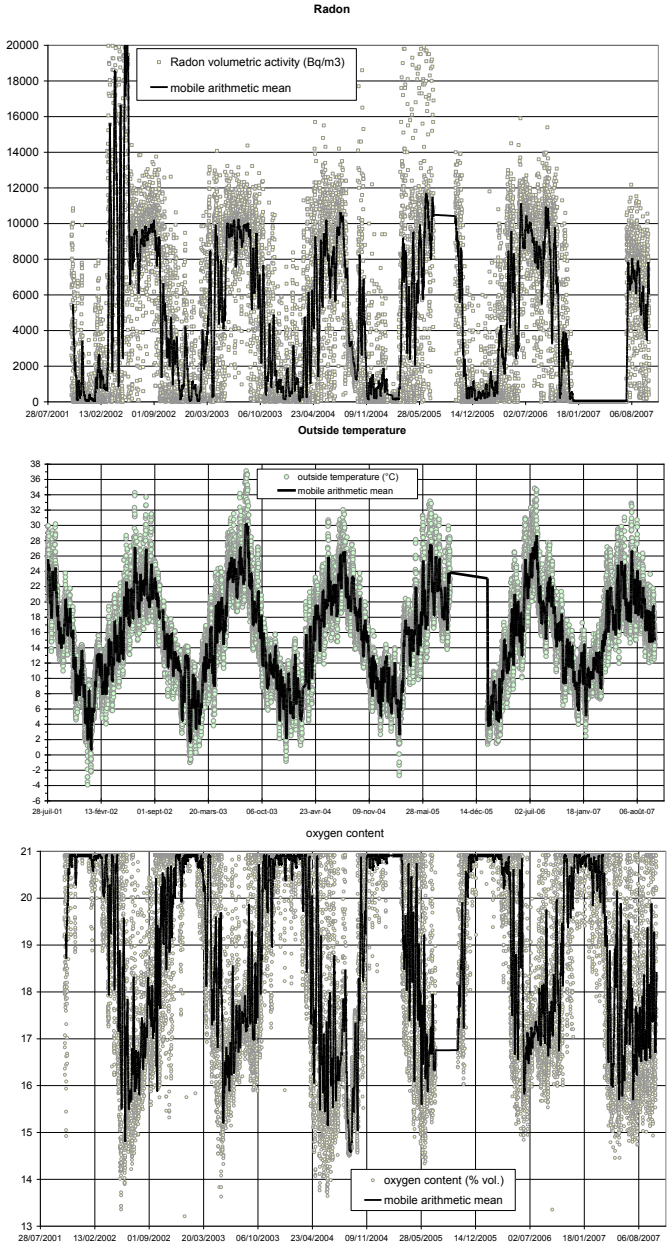

Figure 2. Evolution of the outside temperature, the oxygen content and the volumetric activity of the radon observed in G7 adit connected to the reservoir of Moyeuvre-Grande

5. North basin measures

5.1. Hydrogeological situation

The post-mining reservoir is gradually flooded northward from the deeper works located South. Due to dewatering adits, the final flooding level will reach 207 m NGF. Therefore, an important part of space situated in the northern extremity will remain up flooded. The figure below presents the curve of water rising until September 2007. According to the forecasts, the final level should be reached around beginning of 2008.

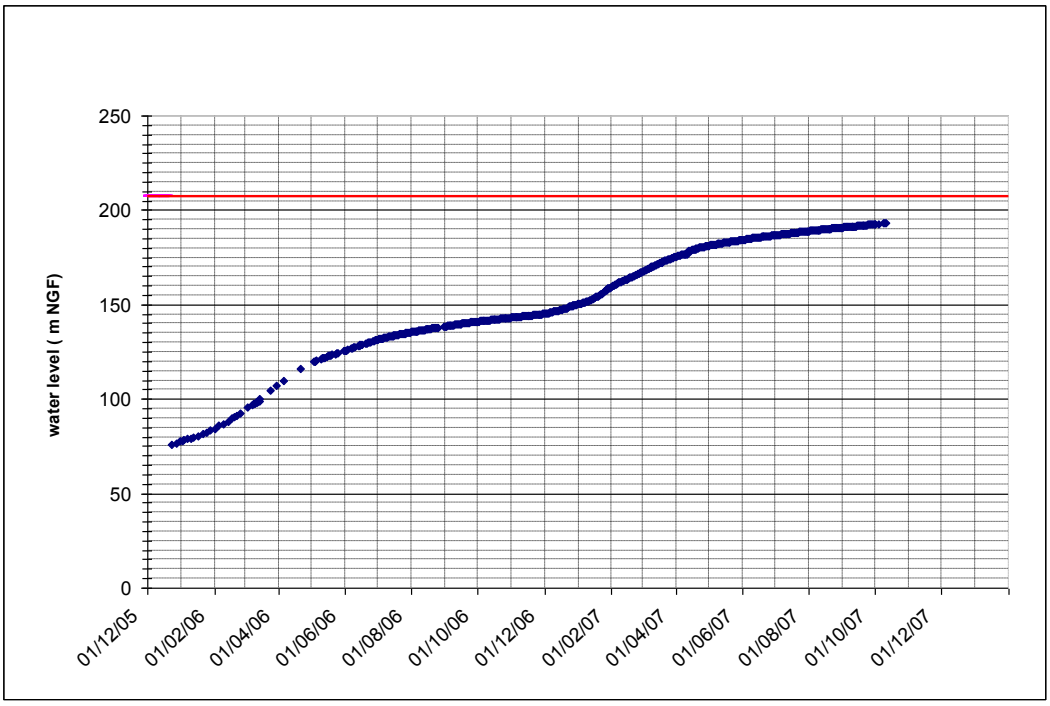

Figure 3. Water level evolution in north iron basin

5.2. Mining openings choice

According to the phenomena observed in Moyeuvre, the circulation between outside and the old mine workings could be mainly governed by the natural thermal draught phenomenon. If this phenomenon is reproduced on the northern reservoir, some openings of this reservoir would be out flowing in summer and would become in flowing in winter and vice versa for other points located at a different level.
A study was carried out by INERIS (Pokryszka, in 2005) to model the importance of circulations in the reservoir of the north basin. The modelisation showed that:

- some openings had an essential role on the gas circulations in the underground network. So, François shaft seems as a main point for the animation of the flow in the whole network, and whatever the season;
- openings located eastern (Ottange 1 shaft, Ottange 2 shaft, Charles Ferdinand roadway and Algrange adit of the former mine Ste Barbe) remain relatively active in summer with a rather homogeneous distribution of the flows. In winter, the flows are globally less important;

- openings located north-western (shaft 1, shaft 2 and shaft 3, St Michel, incline, Ottange incline) present an important activity which is distributed uniformly in winter. In summer, these openings are on the contrary little active.

We took into account these conclusions to select openings to be instrumented: low points located in each of the zones (in the East and in the North-West) defined previously and a high point (cf. map of localisation in appendix 4).

The choice concerned the Algrange adit (Ste Barbe mine), low point located close to the front of flooding (East). The quotation of this opening is near 280 m NGF. To be even closer of the flooding front and to observe all the gaseous phenomena, it was decided to pull the line relative to the gas as far as possible from the entry, inside the workings.

To be in communication as long as possible with the mining space of the underground reservoir, an opening (low point) was chosen northwest of the basin. In this frame, the choice concerned Ottange incline which will stay in communication with the unflooded voids. This opening will remain opened. Its level is around 300 m NGF.

The St Michel incline located northwestern was also selected. Its level is around 315 m NGF.
The François shaft (former shaft for ventilation) was therefore chosen as the high point to be monitored. Its level is around 400 m NGF.

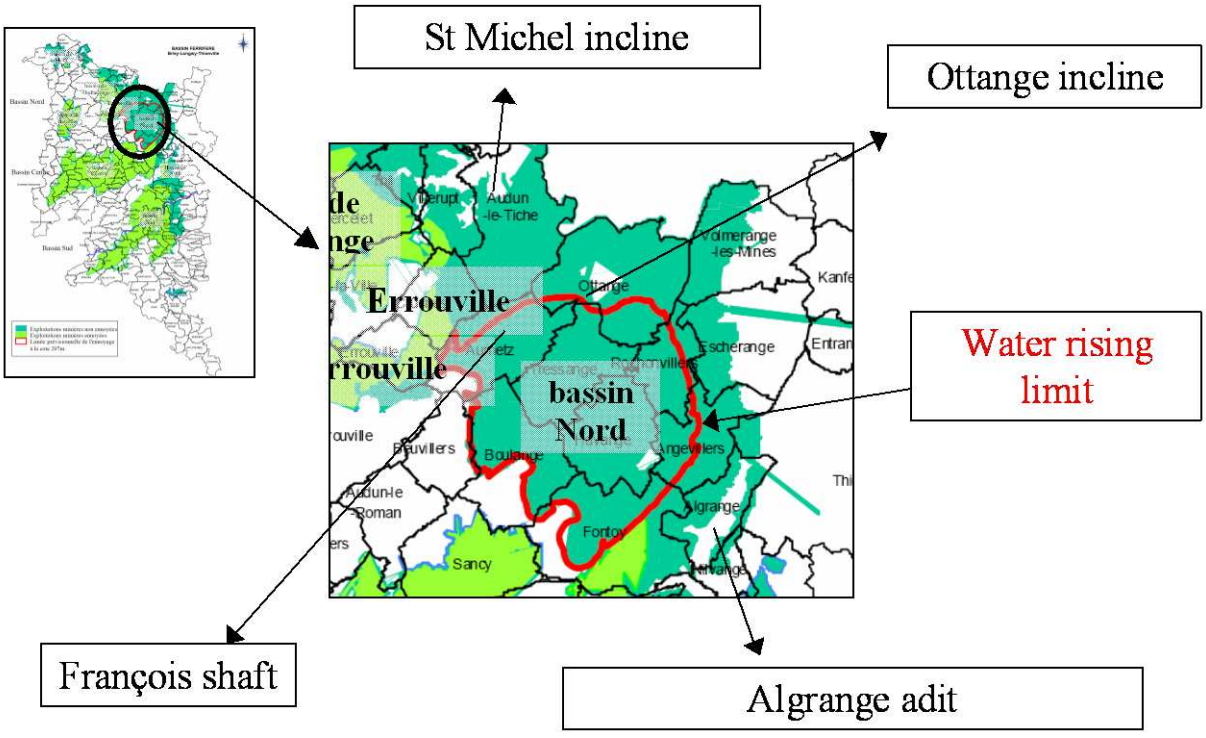

Figure 4. Position of selected openings in the north part of the ferriferous basin of Lorraine

5.3. Observed results

Each opening has a particular behaviour according to the value of the outside temperature (see figure 5). So, Algrange adit and Ottange incline show out flowing when the outside temperature is higher than 15 °C. In summer period, outflows are marked by the presence of radon with volumetric activity reaching about 8000 Bq / m^3 for Algrange adit and about 7000 Bq / m^3 for Ottange incline.

It can be noticed (see figure 5) the presence of CO_2 around 1 to 1,5 % volumic for the Algrange adit and 1 to 1,2 % for Ottange incline. The oxygen content goes down around 18,5 % for the Algrange adit and around 19,3 % for Ottange incline.

For Algrange adit, there is a clear relation between O_2 impoverishment and CO_2 and radon enrichment for temperatures higher than 12-14°C. This relation is not so clear for Ottange incline.

« François » shaft and « St Michel » incline behave rather as high points. In 2006, temperature had to be underneath 5°C to generate large exits of noxoius gas at « François » shaft. During these period, CO_2 content reaches 1,8% vol. and volumetric activity in radon rises until 6000 Bq / m^3. However, outflows of noxious gas are noticed for temperature included between 5 and 10 °C, or equal to 12°C). These gas outflows can last several weeks. For St Michel incline, noxious gas outflow is enriched in carbon dioxide (up to 1,2% vol.) and in radon (volumetric activity around 4000 to 4500 Bq/m^3).

It is also important to underline that over natural events (such as atmospheric variations, wind effect, water rising) add to the natural thermal draught phenomenon and can disturb temporarily the two main stages characterised previously.

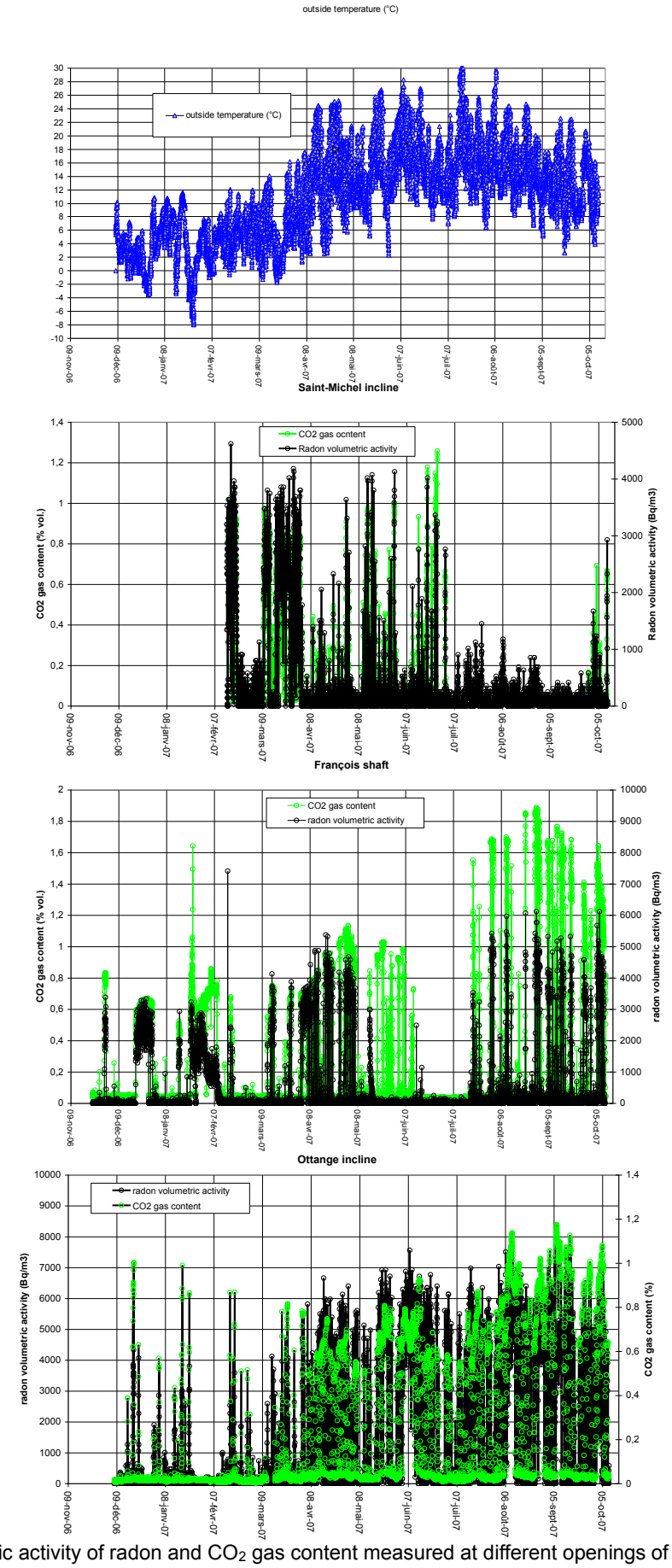

Figure 5. Volumetric activity of radon and CO_2 gas content measured at different openings of north iron basin

A total relation, introduced on figure 6, shows the level of the content of CO_2 measured over several months according to the atmospheric temperature for two openings, the Algrange adit and St Michel incline.
It can be seen the different behaviour of the two openings.
For Algrange adit, the atmosphere enriched in CO_2 appears for temperatures larger than 8-10°C, which corresponds to regime of flux going out of the massif. For St Michel incline, the atmosphere enriched in CO_2 appears for much lower temperatures.

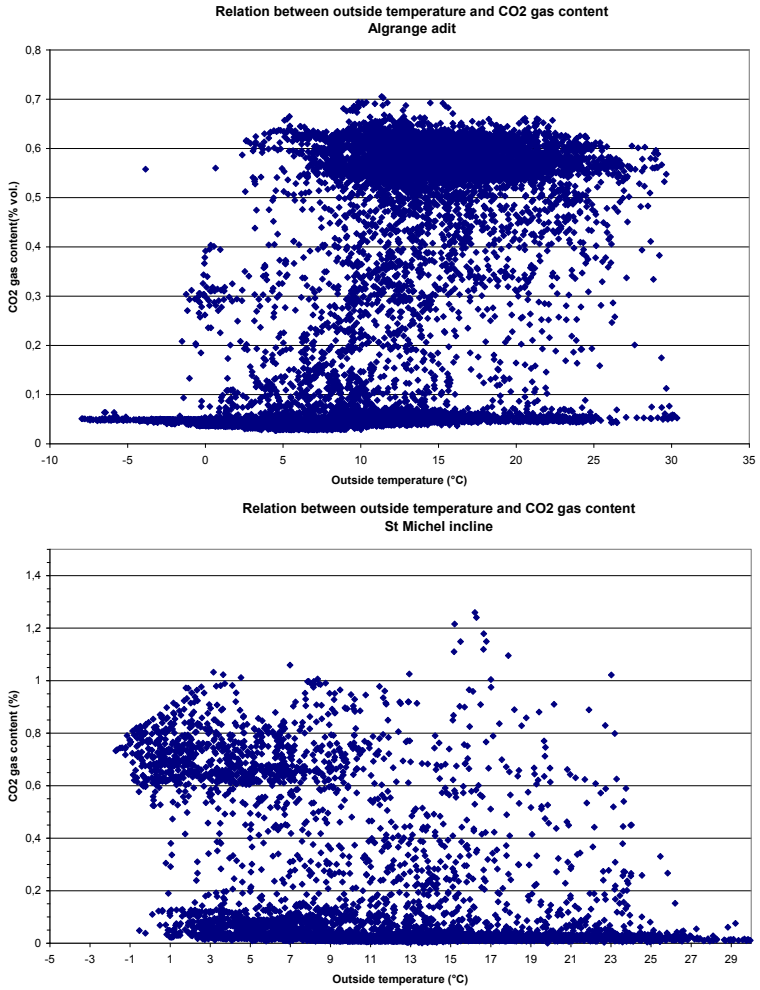

Figure 6. Relation between temperature and CO_2 gas content

6. Conclusion

Gas composition is rather homogeneous on the whole reservoir of northern basin. The outflow of gas seems more or less dependent on the outside temperature value. Some openings behave like high points and other like low points.
The gas, which outflows from north iron basin, is not so rich in noxious gas than the gas observed in Moyeuvre, but the quantity of radon is not negligible.
Natural thermal convection seems to be the main factor governing the flow.
The monitoring will be carried on the different points until the end of flooding as well as few years after in order to observe any variation in gas composition.

7. Acknowledgments

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